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# Toughening Effect and Oxidation Behavior of MoSi<sub>2</sub> -ZrO<sub>2</sub> Composites

Karin Gong\*, Yiming Yao\*, M. Sundberg\*\*, Xin-hai Li\*\*\*\*, Erik Ström and Changhai Li\*

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\*\* Kanthal AB in Sweden

\*\*\* Siemens Industrial Turbomachinery AB in Sweden

\* Dept. of Materials and Manufacturing Technology, Chalmers University of Technology in Sweden

## Objective

In this study, the influence of particle size and volume percentage of unstabilized ZrO<sub>2</sub>-addition on toughening effect in MoSi<sub>2</sub>-matrix composites were investigated. And, the negative effect of ZrO<sub>2</sub>-addition on oxidation resistance of the composites was also observed. The aim of this study is to understand the both of positive and negative effects of ZrO<sub>2</sub>-addition on the composites for reaching a comprehensive results.

## Materials and Preparation

- The commercial Kanthal powder (KT-MoSi<sub>2</sub>) with average size of 2.2 μm in diameter was applied for preparing the composites.
- The Five different USZ- ZrO<sub>2</sub>-particle sizes between 0.74–5.6μm and 10- 30 vol.% of <1 μm particles were used to prepare the testing materials.
- Composites were produced by two different powder metallurgical processes, including pressure-less sintering (PLS) at 1650°C in H<sub>2</sub> for 1 hour and hot-press sintering (HPS) at 1600°C in Ar under 52 MPa for 2 hours.

## Testing

- 1.The hardness and fracture toughness were determined by using Vicker’s indentation technique. And the fracture toughness was calculated by Anstis’equation.
- 2.The specimens were exposed in air under a temperaturer of 1400°C for 100 hours.
- 3.Backscattering electron images of SEM; EDS and XRD methods were applied for the analytical analysis.

Table2. Marks of the MoSi<sub>2</sub> – 20vol.% ZrO<sub>2</sub> composites

Mark of sample	starting powder	sintering process
PLS – 1	KT-MoSi <sub>2</sub> + SF-Extra	Pressure-less sintered
PLS – 2	KT-MoSi <sub>2</sub> + DK-1	as above
PLS – 3	KT-MoSi <sub>2</sub> + SF-premium	as above
PLS – 4	KT-MoSi <sub>2</sub> + DK-2	as above
PLS – 5	KT-MoSi <sub>2</sub> + DK-3	as above
PLS – 6	KT-MoSi <sub>2</sub>	as above

Table 5. Sintered density, room temperature hardness and toughness of five different ZrO<sub>2</sub>-content composites prepared by PLS + HIP processes

Specimen	Sintered density (g/cm <sup>3</sup> )	RT-Hardness (Hv, GPa)	RT-toughness (MPam <sup>1/2</sup> )
HIP-1	6.31 (100%)	9.76 ± 0.20	4.50 ± 0.35
HIP-2	6.34 (100%)	9.64 ± 0.22	6.40 ± 0.35
HIP-3	6.17 (99.5%)	9.13 ± 0.25	5.65 ± 0.54
HIP-4	6.16 (99.5%)	8.96 ± 0.15	6.13 ± 0.41
HIP-5	6.16 (99.5%)	9.00 ± 0.20	5.79 ± 0.24

Table3. Marks; compositions of KT-MoSi<sub>2</sub> + C208-ZrO<sub>2</sub> composites prepared by PLS + HIP processes

Mark of sample	Starting powder (vol. %)	Sintering process
HIP-1	90 vol. %KT-MoSi <sub>2</sub> + 10 vol. % C208	Hot Isostatic Press
HIP-2	85 vol. %KT-MoSi <sub>2</sub> + 15 vol. % C208	as above
HIP-3	80 vol. %KT-MoSi <sub>2</sub> + 20 vol. % C208	as above
HIP-4	75 vol. %KT-MoSi <sub>2</sub> + 25 vol. % C208	as above
HIP-5	70 vol. %KT-MoSi <sub>2</sub> + 30 vol. % C208	as above

## Conclusions

1. The particles of less than 1 μm usually generated the better results on sintered density, RT-hardness and RT-toughness of the composites, compared with the bigger particles.
2. The composites containing 15–25 vol.% USZ-particles showed a better toughening effect, compared to the composites having less or more particles.
3. External pressure of sintering process assisted the composites for a higher hardness, but slightly improved sintered density and toughness only. It means that the PLS process could be a practical and economical method for producing MOSi<sub>2</sub>-ZrO<sub>2</sub> composites in industry.
4. A deteriorated oxidation resistance of MoSi<sub>2</sub>-ZrO<sub>2</sub> composite compared to its monolithic counterpart is due to the formation of the porous oxide layer of ZrSiO<sub>4</sub>+SiO<sub>2</sub> mixture and a retarded Si diffusion.
5. Therefore, an alloying addition for further forming a protective oxide layer is necessary on developing this type of composites.

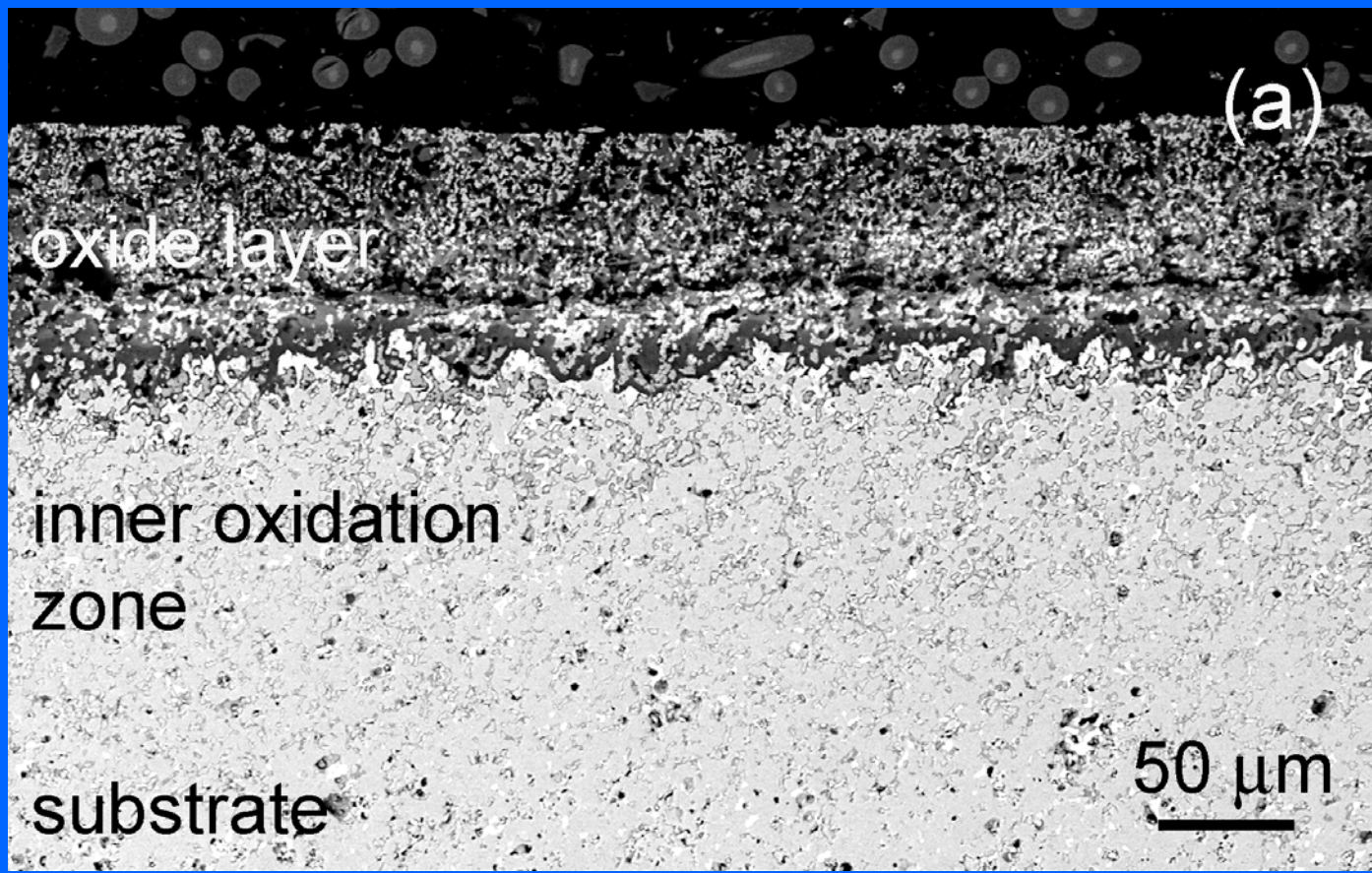


Fig.1 (a) shows the typical microstructures in the oxidized composite and monolithic specimens. The oxidized composite is characterized with a thick oxide layer and an inner oxidation zone with thickness of 110 μm and 200 μm respectively.

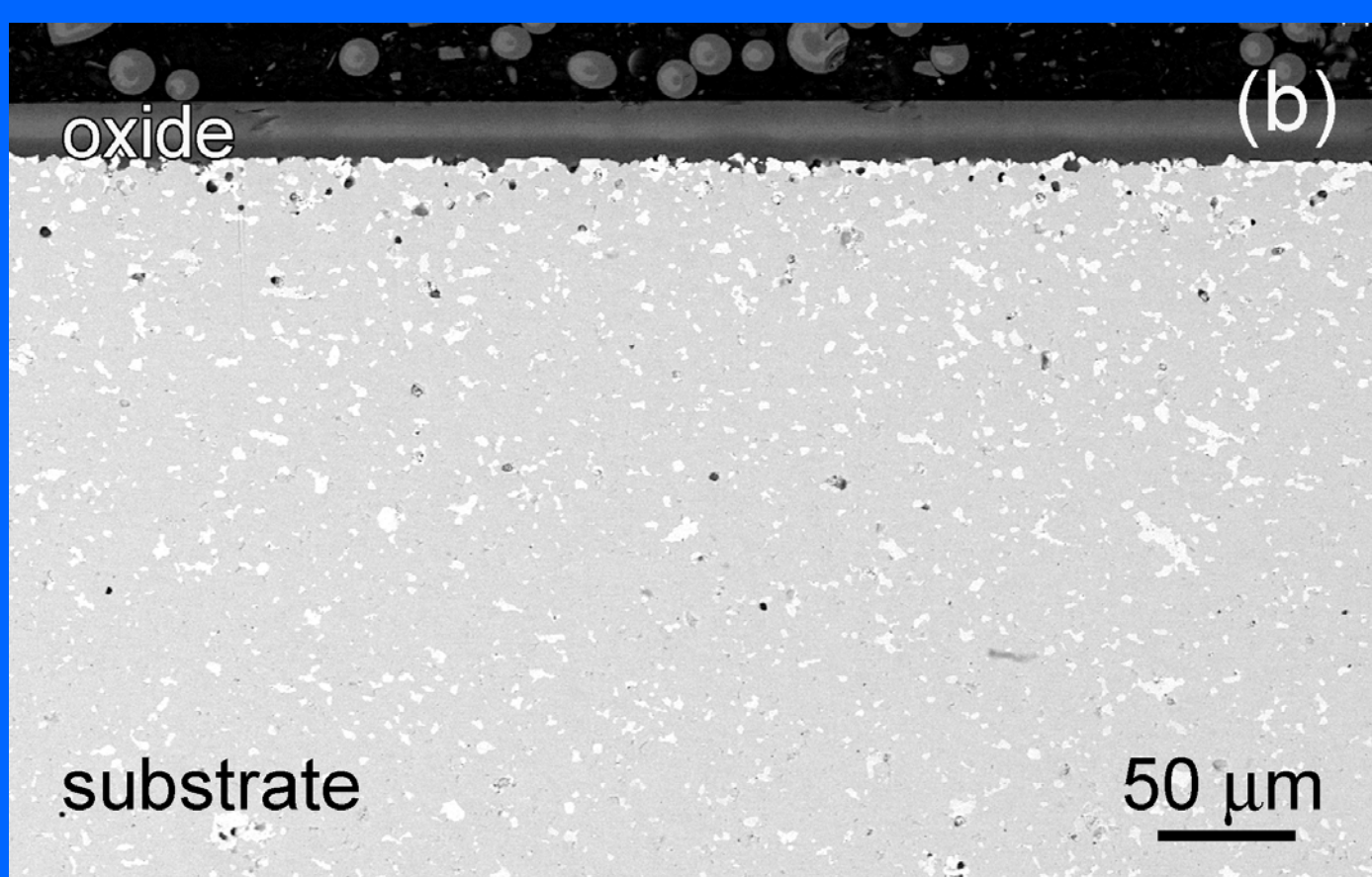


Fig.1 (b) the monolithic MoSi<sub>2</sub>exhibits an excellent oxidation resistance due to a protective silica scale with an average thickness 25 μm, which is under one fourth of that in the composite counterpart. No inner oxidation occurs in the sub-interface region.

Table1. The starting powders of ZrO<sub>2</sub> used for preparing MoSi<sub>2</sub> – 20vol.% ZrO<sub>2</sub> composites

Commercial mark	SF-Extra	DK-1	SF-Premium	DK-2	DK-3
Average size (μm)	0.74	0.87	0.96	2.13	5.65

Table4. Sintered density, room temperature hardness and toughness of MoSi<sub>2</sub> – 20vol.%ZrO<sub>2</sub> composites by PLS process

Specimen	Sintered density (g/cm <sup>3</sup> )	RT-Hardness (Hv, GPa)	RT-toughness (MPam <sup>1/2</sup> )
PLS-1	6.07 (98%)	7.82	5.79
PLS-2	6.13 (99%)	7.80	6.89
PLS-3	6.08 (98%)	7.48	5.63
PLS-4	6.02 (97%)	6.97	4.61
PLS-5	5.89 (95%)	6.01	4.06
PLS-6	6.07 (97%)	9.19	3.09

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